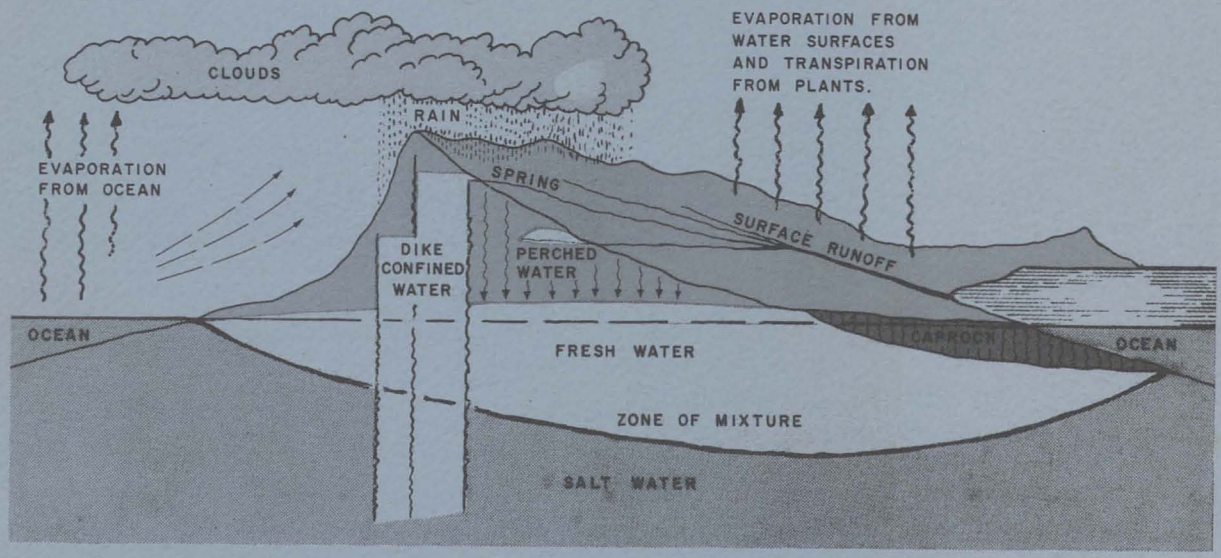
630 US ISSN 0271-9908

Information Text Series 015

HAWAII'S WATER RESOURCES:
Sources, Demands, and Issues

James J. Jacobs



MAY 1983

Hawaii Institute of Tropical Agriculture and Human Resources
UNIVERSITY OF HAWAII

Library of Congress Cataloging in Publication Data

Jacobs, James J.,
Hawaii's water resources--sources, demands, and issues.

(Information text series, ISSN 0271-9908 ;) .
Bibliography: p.
1. Water resources development--Hawaii. I. Title.
II. Series.
TC424.H3J33 1983 333.91'009969 83-8422

TABLE OF CONTENTS

Cover illustration from *Hawaii Water Resources Plan* published by the Department of Land and Natural Resources, State of Hawaii.

Hawaii's Water Resources: Sources, Demands, and Issues

James J. Jacobs[1]

Introduction

Hawaii's water resources are abundant overall. However, the quantity of water available varies considerably geographically. Hawaii's water supplies vary not only from island to island but within each island as well. This variation is primarily due to topography and the northeasterly trade winds. The natural distribution of water resources does not always coincide with the distribution of water uses. As a result, water transport has been used to meet water demands.

A description of Hawaii's water resources and issues surrounding its use is presented in this paper. There are three major purposes behind this report. First, public awareness regarding water is provided through information on the present sources and uses of Hawaii's water resources. Second, the description summarizes existing and potential issues facing the development and use of Hawaii's water resources. Third, the presentation of information and issues serves as a basis for informed participation in the development, evaluation, and implementation of alternative plans for water resource management and development. The wise use of available water resources requires consideration of the hydrology of each island, existing uses, future demands and the potential for and limitations of water management and development plans.

Water Sources

Hawaii's fresh water supply is derived from precipitation on the various islands. Precipitation is one element in the hydrologic cycle.

---

[1]Visiting Professor, Department of Agricultural and Resource Economics from the University of Wyoming, Laramie, Wyoming.

The hydrologic cycle is the constant movement of moisture between the sea, the atmosphere, and the earth, as shown in Figure 1.

This continuous cycle of water on the islands can be traced by starting with evaporation from the ocean surface. Moisture-laden air is carried by northeasterly trade winds to island land masses, where it is deflected upwards by steep mountain slopes. Much of the rainfall results from the cooling of moisture-laden air as it rises up the mountain slopes.

The cycle continues as precipitation reaching the earth's surface takes one of three principal avenues. It may return to the atmosphere through evapotranspiration. It may run off in channels and streams and discharge to the sea. The remainder takes the subsurface route by infiltration to become soil moisture, where it is either used by plants or eventually becomes groundwater in aquifers. Groundwater drains into the sea, too. This continuous cycle of water is interrupted and modified by man's activities; these activities range all the way from urban development to man's multiple uses of water.

The availability of water for domestic, agricultural, and industrial uses can only be determined through knowledge of the various components of the hydrologic cycle: precipitation, streamflow, groundwater, evapotranspiration, etc. Mean annual rainfall for the Hawaiian Islands is about 73 inches, but it ranges from 6.5 to 461 inches. This means that on the average, approximately 21,800 million gallons per day (mgd) of rain falls on the six largest islands. Distribution of this rainfall to evapotranspiration, runoff, and groundwater recharge for the six largest islands is 41, 28, and 31 percent, respectively. Rainfall and its distribution to evapotranspiration, runoff, and groundwater recharge by island are shown in Figure 2.

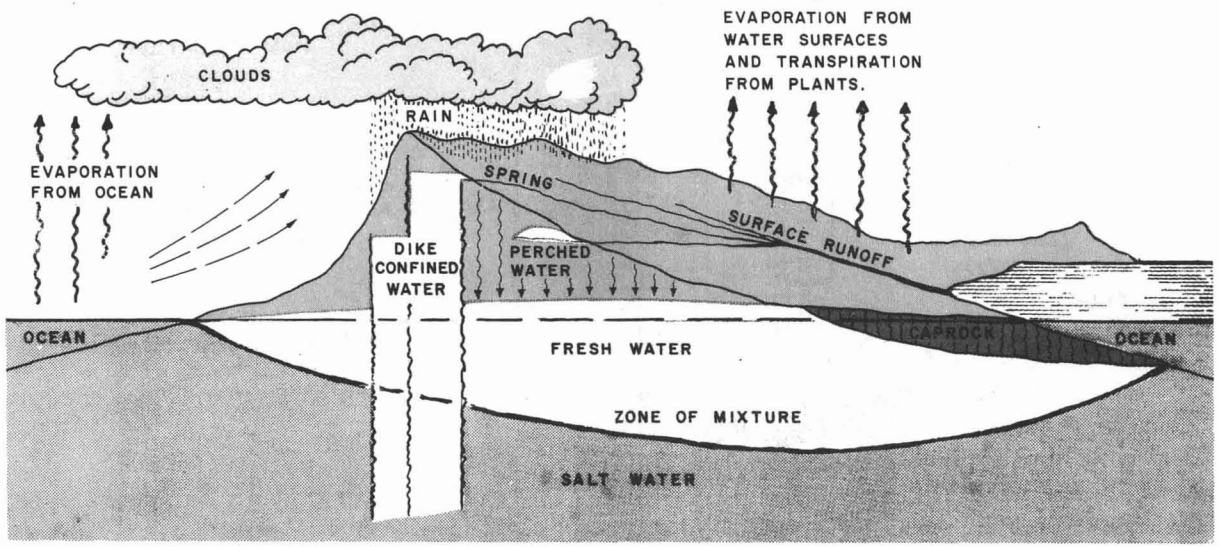


Figure 1. Hydrologic cycle.

Source: Hawaii Water Resource Plan, January 1979.

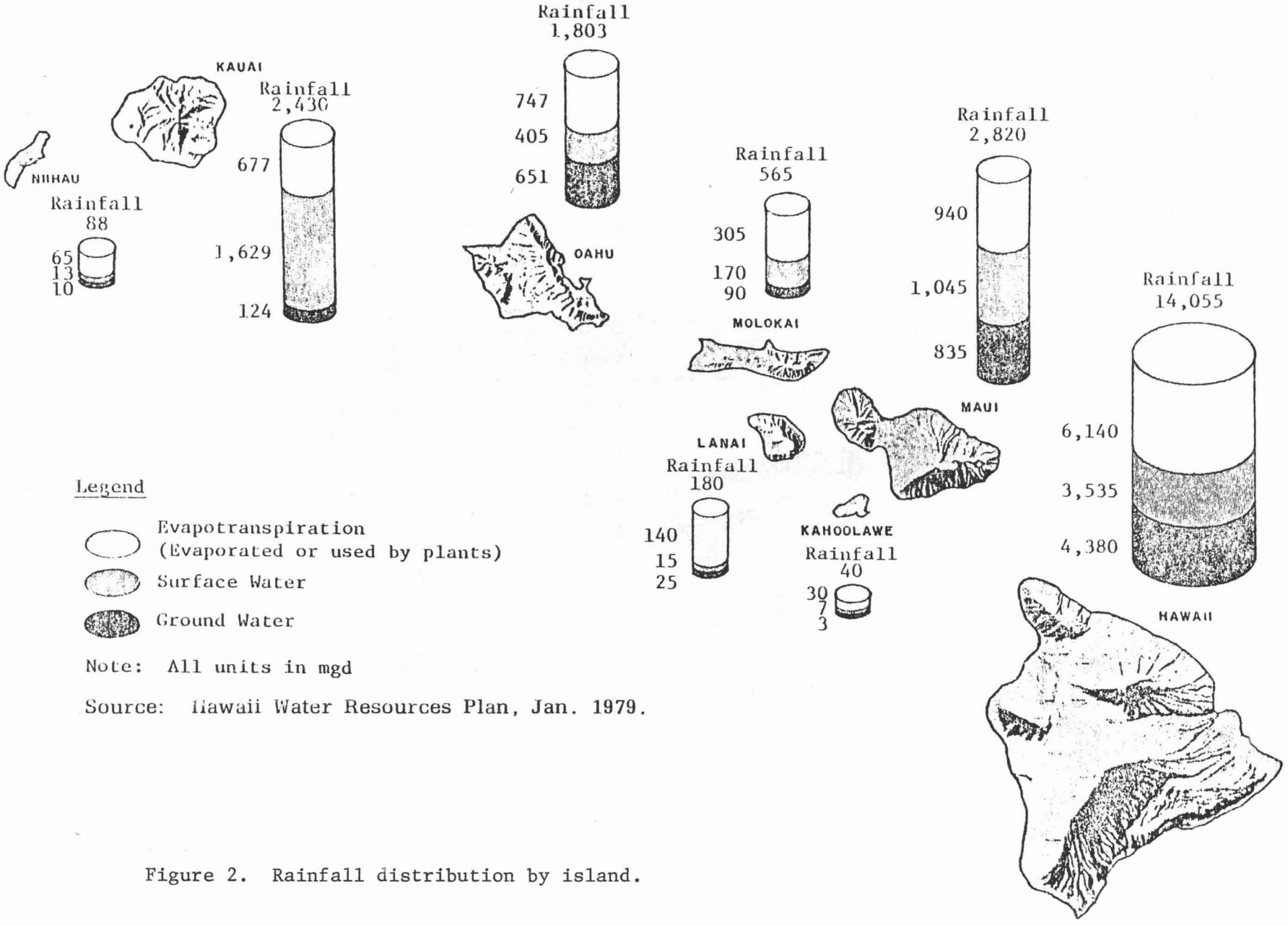


Figure 2. Rainfall distribution by island.

Not all of the surface runoff and groundwater recharge indicated in Figure 2 is available for use through development and diversion. Sustainable yields of water from these sources are substantially less because of technological and economic feasibilities. Sustainable yield has been defined as "The water supply that may normally be withdrawn from a source at the maximum rate which will not unduly impair source utility" (State Water Commission, 1979). Estimates of water, by island, that could be made available for use (i.e., sustainable yields of surface water and groundwater) are presented in Table 1. Rainfall by island and its distribution to evapotranspiration, surface runoff, and groundwater recharge are also shown in Table 1.

Table 1. Rainfall, estimated sustainable yield, and distribution of rain fall to evapotranspiration, runoff, and groundwater recharge

			Groundwater		Surface water	
Island	Rainfall	Evapo-trans-piration	Recharge	Estimated sustainable yield	Runoff	Estimated sustainable yield
			(million gallons per day)			
Hawaii	14,055	6,140	4,380	2,250	3,535	690
Maui	2,820	940	835	720	1,045	439
Lanai	180	140	25	5	15	0
Molokai	565	305	90	63	170	52
Oahu	1,803	747	651	590	405	178
Kauai	2,430	677	124	113	1,629	930
Totals	21,853	8,949	6,105	3,741	6,799	2,289

Source: State Water Resources Development Plan, 1980.

Estimated sustainable yields of surface and groundwater total just over 6,000 mgd, which is 27 percent of total rainfall. Surface water potentially available for use is estimated at 2,289 mgd, which is 34 percent of surface runoff and 10 percent of rainfall. Potentially available groundwater is estimated at 3,741 mgd, which is 61 percent of groundwater recharge and 17 percent of rainfall. These percentages vary considerably from island to island as well as between areas within each island. However, a more important question in terms of water resource development and management is "How do the estimated available supplies compare with existing and projected uses of water?"

Water Uses

Hawaii has developed a water supply system based on water diverted from streams and withdrawn from groundwater sources. History does not record when early Hawaiians built their first auwai (ditch) to irrigate the native staple crop, taro. The first reported ditch (11 miles) constructed to deliver water for irrigating sugarcane was on the Island of Kauai in 1856. In 1878, completion of Hamakua Ditch (17 miles) on the Island of Maui was the beginning of large-scale development of water for sugarcane irrigation. Another historical milestone was the first drilled well completed in late summer of 1879. It was an artesian well struck on the arid Ewa plains of southwest Oahu. Construction of other extensive water development projects followed, particularly those of the sugarcane industry and municipal water utilities.

Water use in Hawaii has been and continues to be dominated by irrigation. The principal use of water is sugarcane irrigation, which exceeds all other freshwater uses combined. However, domestic use is increasing rapidly

because of increased population and tourism. Changes in water use can be depicted by looking at past, present, and projected water uses for Hawaii.

In 1955, gross water use in Hawaii amounted to 545 billion gallons per year, equivalent to 1,493 mgd (Hawaii Water Authority, 1959). The above gross water use figure includes water that is used more than once. For example, water used for hydroelectric power is frequently used later for irrigation. Therefore, net water withdrawals were less than gross water use by approximately 16 percent in 1957 (Hawaii Water Authority, 1959). Distribution of gross water use for 1955 is shown in Figure 3.

Gross water use in Hawaii for 1965 and 1975 was approximately 1,601 and 1,754 mgd, respectively (U.S. Water Resource Council, 1968; Nakahara, U.S. Geological Survey, 1978). The distribution of gross water use for those years is presented in Figure 3. A summary of the quantities of water withdrawn by type of use for 1955, 1965, and 1975 is presented in Table 2.

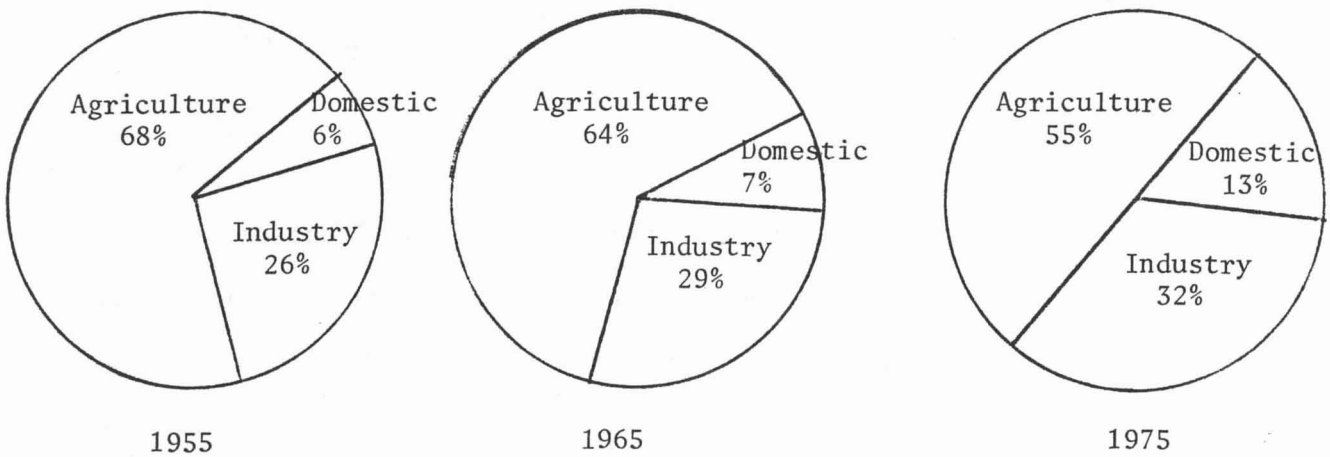


Figure 3. Percent distribution of gross water use by type of use.

Table 2. Quantities of water withdrawn in Hawaii by type of use (mgd)

Use	1955	1965	1975
Domestic and municipal[a/]	86	122	232
Agriculture[b/]	1,020	1,063	970
Industrial[a/]	387[c/]	476[c/]	552[c/]
TOTALS	1,493	1,661	1,754

Sources: Hawaii Water Authority, 1959, Water Resources in Hawaii; U.S. Water Resources Council, 1969, The Nation's Water Resources; Schmitt, 1977, Historical Statistics of Hawaii; and Nakahara, 1978, Water Use in Hawaii, 1975.

[a/] 1955 water use figures for domestic and industrial purposes are averages for the 1954-56 period. Source: Hawaii Water Authority, 1959, Water Resources in Hawaii.

[b/] 1955 water use figure for agriculture is an average of 1950 and 1960 withdrawals. Source: Schmitt, 1977, Historical Statistics of Hawaii. These water use data for agriculture are used rather than those published in Water Resources in Hawaii. The latter source had agricultural use at 1,369 mgd for 1955, which is considerably higher than irrigated acreage and water duties per acre would indicate.

[c/] Includes water used to produce hydroelectric power.

The proportion, but not the quantity, of water used for irrigation has continually declined, particularly during the 1965-1975 period. This decline is also revealed in the daily per capita use of water in Hawaii, which has declined from 3,340 gallons in 1957 to 2,070 gallons in 1975. While this decline is expected to continue, irrigation is still the dominant use in Hawaii. During this same period, domestic and industrial uses of water have increased. A summary of water use by island and type of use

for 1955 and 1975 is presented in Table 3. In addition, there was just over 1,000 mgd of seawater used in 1975.

Table 3. Water use in Hawaii by island for 1955 and 1975 (mgd)

	Domestic		Agricultural		Industrial	
Island	1955	1975[a/]	1955[b/]	1975	1955	1975
Kauai	9	13	325	301[c/]	60	141[c/]
Oahu	60	183	270	238[c/]	81	51
Maui	6	18	393	410[c/]	49	116[c/]
Hawaii	10	17	30	17	197	244[c/]
Molokai	1	1	1	2	*	*
Lanai	*	*	1	2	*	*
TOTAL	86	232	1020	970	387	552

[a/] Domestic use for 1975 includes commercial use.

[b/] Agricultural water use in 1955 was estimated from data published in Hawaii Water Authority, 1959, Water Resources in Hawaii; and Schmitt, 1977, Historical Statistics of Hawaii.

[c/] Agricultural and industrial include the use of recycled water. Recycled water was about 3 percent of total water use in 1975.

Water diverted from surface sources accounted for approximately 60 percent of gross water utilization of the Territory of Hawaii in 1957. Groundwater supplied the other 40 percent of gross water use. In 1975, the primary source of water was reversed, with 51 percent derived from groundwater, 46 percent from surface water, and 3 percent from recycled water.

Water use data show agricultural use of water declining slightly from 1968-75, but overall use is increasing because of increased industrial and domestic demands for water. These increased demands have been met largely through groundwater as the proportion of water supplied by groundwater has increased.

Availability of Water

Total demands for and availability of Hawaii's water resources are summarized in Table 4. It shows that Hawaii's water resources exceed total demands for the predictable future. This is also true of individual islands. It should be noted that for Oahu projected demands are approaching estimated groundwater yields by the year 2000. However, island averages and aggregates tend to mask periodic and local water supply problems.

Table 4. Estimated water and availability by island (mgd)

	Estimated sustainable yield			Water Use	
Island	Groundwater	Surface Water	Total	1975	2000
Hawaii	2250	690	2940	260	310
Maui	720	439	1159	542	614
Oahu	590	178	768	413	590
Kauai	94	930	1024	420	507
Molokai	63	52	115	2	11

Sources: Department of Land and Natural Resources, 1980, State Water Resources Development Plan, Nakahara, 1978, Water Use in Hawaii 1975; Hawaii Water Resources Regional Study, 1979, Hawaii Water Resources Plan.

For example, water supply on Oahu became a major concern during the 1976-77 drought. During this period, conservation practices were undertaken to decrease water use. In some local areas, water is now being imported because demands are already greater than supplies. This problem is illustrated in Table 5, where water yields and uses estimated by hydrographic areas for each island. In particular, area III on Maui and area IV on Oahu have water demands greater than supplies, requiring water importation. It is interesting to note these are dry, sunny areas where sugarcane yields are highest and where much of the population resides. The primary water problem is municipal water supply on Oahu. Additional imports are likely for these areas in the future as well as for other areas of high growth. These data suggest that timing and location of Hawaii's water supplies and demands, not quantity, will be the major difficulties facing the state in planning and managing its water resources.

Another consideration in comparing water availability and water uses is that of water withdrawal versus water consumption. Water withdrawn for a particular use is usually greater than the water consumptively used. A prime example is water used to produce hydroelectric power, where little of the water is consumptively used and is available for reuse by irrigation or other uses. Thus, water deficiencies based on water withdrawals (gross water use) may overestimate net water use (consumptive use) and thereby overestimate the water shortage problem. The continual movement of water and its reuse provide a linkage (interdependence) between water uses. This linkage between uses is another aspect that water managers must consider in solving water supply problems. An example here could be the adoption of a water conserving practice, such as the widely adopted practice of drip

Table 5. Water use and estimated water availability by island and hydrographic area (mgd)

Island	Hydrographic area	Estimated sustainable yield			Water use	
		Groundwater	Surface water	Total	1975	2000
Hawaii	I	200	170	370	52	67
	II	1800	500	2300	190	204
	III	110	0	110	7	15
	IV	100	0	100	5	15
	V	40	20	60	6	9
	Total	2250	690	2940	260	310
Maui	I	85	87	172	104	126
	II	80	107	187	131	137
	III	200	35	235	302	346
	IV	325	180	505	5	5
	V	30	30	60	*	*
	Total	720	439	1159	542	614
Oahu	I	90-120	25	145	7	12
	II	50-70	55	125	15	32
	III	50	10	60	42	124
	IV	225	15	240	235	292
	V	15-25	0	25	5	13
	VI	70-100	73	173	109	117
	Total	590	178	768	413	590
Kauai	I	25	294	319	50	50
	II	22	234	256	131	168
	III	11	170	181	114	124
	IV	17	232	249	27	27
	V	38	0	38	98	138
	Total	113	930	1043	420	507
Molokai	I	39	50	89	*	*
	II	22	2	24	*	*
	III & IV	2	0	2	2	11
	Total	63	52	115	2	11

Sources: Department of Land and Natural Resources, 1980, State Water Resources Development Plan, Nakahara, 1978, Water Use in Hawaii 1975; Hawaii Water Resources Regional Study, 1979, Hawaii Water Resources Plan.

irrigation in Hawaii. Drip irrigation increases the efficiency of water delivery to a crop. However, it also reduces the quantity of water lost by seepage and could thereby reduce the sustainable yield of an underlying groundwater aquifer. These linkages or interdependencies between uses must be considered and their impacts evaluated in suggesting water management practices.

Water supply, use, and availability data suggest that Hawaii possesses a wealth of water. However, the public's interest in and concern over water resources appear to have intensified. This increased concern can be partly explained by isolated water supply problems, knowledge of increased demands for water, and emphasis on environmental values. It also suggests that Hawaii's primary water problem is one of allocation and not quantity. The next section attempts to identify and discuss primary issues in dealing with the allocation problem.

Water Issues and Management

The Hawaii State Legislature in 1975 expressed a need for a statewide plan to express Hawaii's desired future and the wise use of resources in obtaining that future. On May 22, 1978, Hawaii's State Plan, which formulated a long-range guide, was signed into law. Water resources development is one of twelve subjects required to be covered by a functional plan to further detail the State Plan. The Department of Land and Natural Resources had the lead role in developing a functional plan for water resources. Objectives, policies, and implementing actions of the functional plan for water resources are found in the State Water Resources Development Plan (Department of Land and Natural Resources, 1980).

It is interesting to note that the objectives in the functional plan for water resources correspond quite closely with the major water problems and issues identified by the State Water Commission. This Commission was appointed by the governor in mid-1977 in response to public concern over water supplies. The Commission decided to concentrate on the following major issues: (1) assessing water supply and demand, (2) water for agriculture, (3) water for environmental and social values, (4) regulating water use, (5) water rights, (6) information needs, and (7) financing water programs and projects.

These water problems and issues are basically the objectives expressed in the water resources development plan. The immediate question facing the state is "How can these objectives best be accomplished?" In attempting to answer that question, two major water resource problems or issues can be identified that cut across all the objectives. These two problems are (1) assessing water supplies and demands, and (2) water management and regulation.

The assessment of water supplies and demands is much more involved than just measuring the quantity of water available and the quantity of water withdrawn. Assessment of a water management practice also needs to consider the related aspects of (1) consumptive use, (2) water quality, and (3) linkages and associated impacts among uses. To illustrate, take the previous example of the state's adoption of drip irrigation. While drip irrigation increases the efficiency of water delivery to a crop, its effect on the crop's consumptive use is minimal. In terms of water quality, drip irrigation should improve water quality relative to surface irrigation, particularly for surface water. There are also potential impacts of the

adoption of drip irrigation because of the linkages among water uses. As indicated earlier, drip irrigation increases the efficiency of water delivery to the crop, thereby reducing the quantity of irrigation water used. This in turn reduces the quantity of water moving through seepage into groundwater aquifers and return flows into surface water. Such reductions may affect subsequent users of that water resource. Identification and assessment of these impacts are extremely difficult because of the limited knowledge concerning the relationship between man's activities and their effects on water resources in terms of quantity, quality, timing, and location. These aspects of water resource planning and management decisions need to be given more consideration in improving the use of the state's water resources.

Water rights have long been a controversy in Hawaii. Water rights in Hawaii are historically related to the land tenure system. Land in ancient Hawaii was controlled by chiefs, who held it as trustees and shared it with lower chiefs and commoners for their mutual benefit. The native Hawaiians built irrigation systems in developing the land. In these systems, water was allocated according to a farmer's needs and the amount of labor each had contributed toward building and maintaining the system of ditches. Thus the chief was also a trustee of water with the people as beneficiaries.

The ancient Hawaiian land tenure system could not accommodate the wishes of Westerners. Consequently, during the Mahele period (1845-1855), a legal foundation for a system of private ownership of property was established. Along with this private ownership of land was the question of water rights. Whether chiefs intended to transfer their water along with their land is not clear. The Laws of 1842 and the 1850 Kuleana Act contain language concerning the water rights of common people and preserving the chiefs' authority over water.

Legal authorities seem to have tried to distinguish between water rights and land ownership, but case law, on which Hawaii surface water rights are based, tends to support private landowners' claims that surface water is their own. In terms of groundwater, the doctrine of correlative rights applies, which permits a landowner to draw a reasonable share from an underlying aquifer, subject to the rights of others. The major controversy remaining regarding Hawaiian surface water rights is the question of state or private ownership of surplus water.[a/] This question was highlighted in 1973 in the case of McBryde Sugar Co. vs. Robinson. The State Supreme Court ruled that Hawaiian chiefs did not intend to give away water rights when the land was distributed beginning in 1846. As a result, the 1973 court ruled that stream water belongs to the state, subject to appurtenant and riparian rights.

Private landowners viewed the 1973 ruling as a taking of private property and appealed to federal court. U.S. District Court ruled that Hawaii's Supreme Court decision did deprive landowners of their property interests in water. The state then filed an appeal of the District Court's decision in the U.S. Court of Appeals for the Ninth Circuit. This issue is still unresolved and is frequently cited as a major reason why the state should delay the development of any water statute and regulation system.

The ruling in McBryde vs. Robinson was confusing because it revised two major premises regarding surface water rights. First, the Court held

---

[a/] There is agreement that persons who owned land and had received water under the Hawaiian system prior to 1848 had a right to water for their lands. This water right is called an "appurtenant" water right. Cases also have referred to "riparian" water rights, which are rights of landowners whose land is adjacent to a running stream. The water remaining after appurtenant and riparian water rights has become known as surplus water.

that all water other than that falling under appurtenant and riparian water rights belonged to the state. Second, the court held that water rights could not be separated from the land, so water could not be transferred out of a watershed. While the ruling is confusing and reverses two general beliefs, it does not suggest that the state should take a "go slow" approach to water regulation. In fact, it may be taken as indication that the state needs to develop a water statute and regulation system.

As demands on Hawaii's water resources increase, the conflicts among water uses will intensify because of limited water availability (quantity, quality, location, time) and the linkage (interdependence) among uses. It appears there is need for a state water regulation system to provide a framework for water allocation decisions. Just because a statute indicates that the state holds most water resources in trust, it does not necessarily imply that it will sell those water rights. Rather, it would act as a trustee and issue water rights as they are applied for, subject to the quantity of water available and impacts on existing uses. Such a regulatory system should be regarded as supplemental to the marketplace. Use of the marketplace to allocate water resources, within a water rights framework, may well be preferred to resolving future water conflicts by court decisions.

To take a positive vein, what does a state water rights market approach have to offer? First, one of the major water resource problems is that of assessing water supplies and water uses. A water rights system would help in identifying water uses and the quantity used through applications for water rights. This would provide the state with a means for tabulating water uses in terms of both quantity and location. It should also be useful in beginning to identify the linkages (interdependencies) between water uses.

The other major problem is that of allocating (managing) the state's water resources. Alternatives for managing water sources to meet increasing demands are numerous. These management alternatives can be placed into four categories: (1) developing new water sources, (2) recycling waste water, (3) water conservation, and (4) reallocation of water among uses. Some of these practices are beginning to take hold in Hawaii at the present time. The use of flow restrictors on showers, drip irrigation, and using waste water for irrigation are a few of the examples.

As demands continue to increase, water supply limitations and the cost of developing new water supplies will lead to a change in emphasis from developing new water supplies to the other three categories. This means the emphasis will be on managing existing water supplies. A system for identifying water rights and the marketing of water (water pricing) will play a central role in managing existing water supplies. Take, for example, the major water demand problem of Hawaii, which was identified earlier as municipal demands on Oahu. Water pricing could be used to encourage water conserving practices, thereby decreasing per capita consumption and reducing the increase in water demands. A water rights system should help in reallocation of existing water uses to municipal uses through the marketplace, within established regulatory guidelines.

In summary, Hawaii has sufficient water resources to meet its predictable future demands. Hawaii's problems in meeting its water demands will be primarily due to (1) location of demand relative to supply, (2) interdependencies (linkages) between water uses, and (3) reallocation of water among uses. To aid in resolving these problems and obtaining sufficient water supplies at reasonable costs, the state needs to develop a means

for (1) assessing water supplies and demand (including interdependencies between uses), and (2) encouraging the adoption of water pricing in managing water use. Enacting statutes to establish water rights could provide a means for quantifying water use by type and location of use. These statutes could also establish procedures for transferring water rights. The combination of statutes and emphasis on water pricing should result in a more appropriate set of management practices in alleviating the water resource problems facing Hawaii.

References

Department of Land and Natural Resources. September 1980. State Water Resources Development Plan. Honolulu, Hawaii.

Fujimura, Faith N., and Williamson B.C. Chang (eds.). 1981. Groundwater in Hawaii: A Century of Progress. Water Resources Research Center, University of Hawaii at Manoa, University Press of Hawaii.

Hawaii Water Authority, March 1959. Water Resources in Hawaii.

Hawaii Water Resources Regional Study. January 1979. Hawaii Water Resources Plan. Honolulu, Hawaii.

Nakahara, R.H. October 1978. Water Use in Hawaii 1975, Report R58. U.S. Geological Survey and Department of Land and Natural Resources, Honolulu, Hawaii.

Schmitt, R.C. 1977. Historical Statistics of Hawaii. University Press of Hawaii.

State Department of Budget and Finance. January 1979. Land and Water Resource Management in Hawaii. Honolulu, Hawaii.

State Water Commission. January 1979. "Hawaii's Water Resources: Directions for the Future," A Report to the Governor. Honolulu, Hawaii.

U.S. Water Resources Council. 1968. The Nation's Water Resources.

U.S. Water Resources Council. December 1978. The Nation's Water Resources 1975-2000, Vol. 4: Hawaii Region.

Hawaii residents may order **single copies** of this publication free from county offices. **Out-of-State** inquiries or bulk orders should be sent to the Agricultural Publications and Information Office, College of Tropical Agriculture and Human Resources, University of Hawaii, 2500 Dole Street, Krauss Hall 5, Honolulu, Hawaii 96822. Price per copy to bulk users, 90 cents plus postage.

NOTE: As part of a structural reorganization, the Hawaii Agricultural Experiment Station and the Hawaii Cooperative Extension Service have been merged administratively under the name HAWAII INSTITUTE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, College of Tropical Agriculture and Human Resources, University of Hawaii.

Hawaii Institute of Tropical Agriculture and Human Resources
College of Tropical Agriculture and Human Resources, University of Hawaii
Noel P. Kefford, Dean of the College and Director of the Institute
HITAHR INFORMATION TEXT SERIES 015—05.83 (1M)